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The Acoustic Model Evaluation Committee (AMEC) Reports

Volume I. Model Evaluation Methodology and Implementation (U)

Richard B. Lauer

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Ocean Science and Technology Laboratory

September 1983

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Foreword (U)

(U) The Acoustic Model Evaluation Committee (AMEC) has been chartered to serve as an advisory group to the Director, Naval Oceanography Division (OP-952), on matters dealing with model evaluation. In fulfillment of its charter AMEC will produce a series of reports detailing the results of model evaluations. This first volume describes the methodology selected and the manner in which it has been implemented. Subsequent volumes will present the results of specific evaluations. Application of the methodology leads to information on the physics, algorithms, numerical techniques and computer-related questions of use to program managers, scientists, system designers, and fleet users. Model errors and deficiencies are given as are recommendations for model improvements. These findings are supported by test cases that include comparisons with data sets representing a broad range of environmental and acoustic conditions.

G. T. Phelps

G.T. Phelps, Captain, USN
Commanding Officer, NORDA

Executive Summary (U)

(U) The Acoustic Model Evaluation Committee (AMEC) has adopted an interim methodology for the evaluation of propagation loss models. The methodology consists of providing the following information: (a) model description, (b) physics and mathematics, (c) run time, (d) core storage, (e) complexity of program execution, (f) ease of effecting program alterations, (g) program implementation on a different computer, (h) cognizant individual(s) or organization element(s), (i) byproducts, (j) special features, and (k) references. The accuracy of the model is assessed by quantitative measures of comparison with reference experimental data sets, other models, and closed form solutions. Two techniques are used: The difference technique, whereby differences between the model and a reference are statistically given in various regions (e.g., direct path, bottom bounce, convergence zone); and the Figure of Merit (FOM) technique, whereby detection coverage as given by the model and a reference data set are compared as a function of Figure of Merit. The basic intent of model evaluation is to provide model users, sonar system designers, and those who select models for use in making sonar system performance predictions with basic information on a model including its physical foundations, domains of applicability, software configuration, and machine dependencies so that the best match between acoustic model and sonar application may be achieved.

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Acknowledgments (U)

(U) The author wishes to acknowledge the valuable contributions of Dr. F. R. DiNapoli of the Naval Underwater Systems Center, New London, Conn., while he was chairman of the Panel on Sonar System Models (POSSM) for his support of the development of the model evaluation methodology adopted by AMEC on an interim basis. The stimulating discussions with Dr. A. L. Anderson, formerly of the Naval Ocean Research and Development Activity, resulted in many refinements of the model evaluation methodology and the concept of having a portable test package for model evaluation. This volume and its successors, giving the results of specific model evaluations, would not have been possible without the support and direction given by Mr. R. Winokur during his tenure in OP-095E and 952D. Dr. M. C. Karamargin of the Naval Underwater Systems Center, New London, is well deserving of praise for editing and organizing a vast amount of environmental and acoustic data, running the acoustic models, and producing all the figures and quantitative accuracy assessment results by the "difference technique." Finally, my thanks to the members of AMEC for valuable insight and for recommendations that have substantially increased the quality and the practicality of the model evaluation effort.

Contents (U)

The Acoustic Model Evaluation Committee (AMEC) Reports
Volume I. Model Evaluation Methodology and Implementation (U)

1.0 (U) Introduction

(U) This report is the first of a series presenting the results of the Acoustic Model Evaluation Committee's (AMEC) evaluation of specific environmental acoustic models intended for operational use or system design. This first volume presents the AMEC charter and the approach chosen for the fulfillment of that charter. The methods used in model evaluation will evolve with experience gained and the addition of new evaluation concepts and techniques; the data base used for model comparison will be added to until it is representative in terms of acoustic parameters (e.g., frequency, source depth, receiver depth) and tactical scenarios (e.g., ocean basin, bottom loss province types, existence of surface ducts); models will be changed and will require partial reevaluation. Each volume presents a standalone evaluation of a specific model. A given model is not provided a "seal of approval"; rather, information is provided that may enable a program manager, project engineer or research scientist to determine if a model is adequate for a specific application and to compare various evaluated models in order to select the optimum model. It should be noted at the outset that no single model may be optimum for all applications since, for example, some applications emphasize speed over accuracy, others pertain to a given frequency extent, and others require outputs beyond those ordinarily available. Specific recommendations for model improvements are made in those instances where the improvements would not alter the basic characteristics of the model (e.g., not substantially increase running time) except in cases where errors have been found.

(U) Errors in a model are noted when discovered and corrections given. The philosophy and approach outlined in this volume apply to propagation loss, ambient noise and reverberation models. The specific treatment and examples are for propagation loss models, with emphasis on propagation loss models employing range independent environmental inputs.

2.0 (U) Proposed Charter for the Acoustic Model Evaluation Committee

(U) Purpose: The purpose of the Acoustic Model Evaluation Committee (AMEC) is to ensure that basic ocean acoustic and related environmental models are properly evaluated, so that the Navy will have confidence in the results and an understanding of the limitations of acoustic models being used to support fleet operations and system design and analysis studies. The AMEC will serve as an advisory group to the Director, Naval Oceanography Division (OP-952), on matters dealing with model evaluation. Basic acoustic models include propagation, ambient noise, and reverberation models.

(U) Operations: The AMEC will establish guidelines, methods, and criteria for testing and evaluating candidate models, and will ensure that these guidelines, methods, and criteria have been followed before certifying models as properly evaluated, and will provide guidance for operational use. Actual testing and evaluation is to be performed jointly by AMEC and the developing organization.

(U) The AMEC Chairman reports to the Director, Naval Oceanography Division (OP-952).

(U) Membership: Members of the AMEC are drawn from the technical community composed of Navy and university laboratory personnel who have extensive experience in environmental and acoustical modeling. The AMEC will meet as directed by the AMEC chairman, but at at least three times annually.

(U) Functions: The AMEC is responsible for the following functions:

- (U) The AMEC will establish standardized guidelines, methods, and criteria by which ocean acoustic and related environmental models may be tested and evaluated.
- (U) The AMEC will review the results of tests and evaluations of candidate models to ensure applicability and suitability for operational use.
- (U) The AMEC will review documentation of evaluated models, including users manuals, for completeness and clarity.
- (U) The AMEC will continually review the status of the ocean acoustic modeling effort to determine deficiencies, and to ensure early identification of model requirements for emerging systems.
- (U) The AMEC will advise cognizant program managers relative to model evaluation and model requirements.
- (U) The AMEC will certify satisfactorily evaluated models as Navy Evaluated Models, specifying confidence limits and limitations, if any.
- (U) The AMEC will identify data sets for use in model evaluation.

3.0 (U) The Role and Approach of the Acoustic Model Evaluation Committee

(U) The Acoustic Model Evaluation Committee's (AMEC) primary function is the evaluation of ocean environmental and acoustic models intended for operational use and the design of systems. The scope of evaluation encompasses ocean environmental data bases and models, the basic acoustic building block models of propagation loss, ambient noise and reverberation levels, system performance models and engagement models. In all cases, AMEC evaluation is limited to the environmental and acoustic components of any model. Initial evaluation efforts have focused on propagation loss models utilizing range independent environmental inputs. The evaluation methodology developed for range independent propagation loss has also been deemed applicable for range dependent propagation loss models.

(U) In fulfillment of its charter, the AMEC effort consists of simultaneous tasks in four major areas: (1) the establishment and refinement of a model evaluation methodology suitable to each model type (e.g., propagation loss with range dependent inputs, directional ambient noise); (2) the identification, acquisition, and use of data sets suitable for the quantitative assessment of model accuracy; (3) the development of a portable test package to assure uniformity of model evaluations in a timely, low cost manner; and (4) the performance of model evaluations.

(U) The evaluation of environmental or acoustical models is a joint endeavor between the model developer, or an individual or organizational element claiming responsibility for the dissemination and maintenance of the model, and the AMEC through an appropriate subcommittee or designee. The responsibilities are delineated as follows:

- (U) Documentation: The model developer provides model documentation in accordance with requirements as given in the paragraph entitled "References" on page 7. This response is reviewed by AMEC for completeness, clarity, and correctness. Following discussions between the AMEC representative and the model developer, the documentation is altered and amended as necessary, and submitted for AMEC approval.

• (U) Test Cases: Test cases selected by AMEC are run by the model developer. These test cases are a subset of those available to AMEC, consisting of experimental acoustic data supported by environmental data, environmental acoustic scenarios (the intent here is to compare acoustic results with those of an appropriate reference model and diagnose the causes of significant discrepancies), and closed form solutions. Further test cases are based upon an examination of the physics and mathematics of the model by an independent expert (see below). The test cases are meant to reflect the model's intended applications and stated domains of applicability and limitations. They are to be produced in a prescribed format with other supporting information (e.g., run time). The environmental inputs are supplied by AMEC. If input or output requirements cannot be met by the model to be evaluated, agreed upon alterations may be made following discussions between the model developer and AMEC. (Note: such problems and alterations are to be fully documented and included in the final report.)

• (U) Accuracy Assessment: The results of test cases are compared to experimental data, results of a reference model, or closed form solutions, as appropriate. The comparisons are quantitative and are performed under AMEC control using approved AMEC techniques. (Note: The accuracy assessment techniques and test cases are evolutionary; therefore, refinements and additions are expected with the passage of time.)

• (U) Physics and Mathematics Examination: An examination of the model's foundations in terms of its physics and mathematics are undertaken by an expert selected by AMEC. Particular attention is given to aspects of the formulation, especially assumptions and approximations that may tend to limit the model's domain of applicability. Such limitations should be tested by the identification of appropriate test cases, the running of these cases by the model developer and, finally, the comparison of the results with those of a reference model, if available.

4.0 (U) The Mechanics of Model Evaluation: A Multi-State Process Requiring a Portable Test Package

(U) The portable test package is needed for the simultaneous evaluation of several models. The evaluations are to be carried out expeditiously while retaining AMEC control of certain crucial steps, particularly those involving comparison of model results with representative data sets retained by AMEC for the purpose of accuracy assessment. It is also essential that all analyses functions incidental to model evaluation be performed under supervision of, and review by, AMEC. Efficiency and control are achieved by a two-stage model evaluation. Stage I is fulfilled by the model developer or persons at the developing activity; Stage II is carried out by designees of AMEC.

(U) In Stage I, the model developer provides user-oriented information by means of filling out a model information form. The areas covered include: (1) model description comprising the model's purpose, input/output information, systems presently using or intending to use the model; (2) core storage requirements (including assumed number of bits per word); (3) a flow chart; (4) a program listing; (5) a list of computers on which the program is running; (6) special requirements such as computer language, special codes (e.g., for plot generation), word length, and library routines; (7) a list of any versions of the program extant which differ from that undergoing evaluation and the exact nature of the differences; (8) definition of all parameters used in running the program including default values and guidance for the selection of any unusual parameters; (9) the name(s) of cognizant individual(s) or organizational elements who formulated the program, were responsible for its computer implementation and are now responsible for program maintenance; (10) references,

including user's guides, response to SECNAVINST 3560.4, and specific algorithms used; (11) additional information produced in addition to the main function or as a byproduct; and (12) special features (e.g., ability to impose source and receiver beam patterns in propagation loss models or availability of a frequency interpolation scheme). Also in stage I, the model developer runs the model for test cases specified by AMEC. Inputs to the model and output format are specified by AMEC. If for some reason the model cannot utilize the inputs in the form given or cannot produce the required output, mutually agreeable alterations will be found and documented, including the reason(s) for the inability to follow the original request. The test cases will be designed to evaluate the model's accuracy over a broad range of representative environmental scenarios. Test results are to be returned to AMEC in the specified format in addition to run decks for a specified subset of cases and running time for all cases.

(U) Stage II of model evaluation consists of an AMEC designee compiling the results from stage I. This compilation is followed by analysis of the model information form results for completeness and clarity. Areas identified as incomplete, unclear or of questionable validity are resolved in a second iteration with the model developer. Results of the test cases are compared with data (experimental, closed-form solutions and results of "reference" models) compiled by AMEC. The result of this process is a quantitative assessment of model accuracy over representative scenarios. Where possible, discrepancies are analyzed, model deficiencies or limitations identified and recommendations for model improvement given. The quantitative accuracy assessment of Stage II is performed by means of AMEC-approved techniques that have been computer implemented.

(U) For propagation loss model evaluation, AMEC has adopted, on an interim basis, the evaluation methodology developed by the Panel on Sonar System Models (POSSM) as given in Lauer and Sussman (1976, 1979). The quantitative accuracy assessment algorithms and associated graphics are contained in a computer program known as MCPRO (Sussman and Oberlander, 1979). This program, originally developed at the New London Laboratory, Naval Underwater Systems Center, has been disseminated to the Naval Ocean Systems Center and the Naval Ocean Research and Development Activity. Data tapes for use in accuracy assessment are to be generated for each model type (i.e., range independent propagation loss (RIPL), range dependent propagation loss (RDPL), directional ambient noise (AN) and reverberation level (RL)). Together, these tapes will likewise be disseminated. The program MCPRO and the tape of data sets for range independent propagation loss model accuracy assessment will constitute a portable test package for use in stage II of the evaluation process.

5.0 (U) Elements of Model Evaluation

(U) Each model evaluation (to be reported in subsequent volumes of this series) consists of a number of elements that will provide information which should be of assistance in selecting a model for a given application. These elements are:

- Model Description
- Physics and Mathematics
- Run Time
- Core Storage
- Complexity of Program Execution
- Ease of Effecting Program Alterations
- Ease of Implementation (On a Different Computer)
- Cognizant Individual or Organization Elements
- References
- Byproducts
- Special Features
- Accuracy Assessment (Quantitative)

(U) In the following sections, each evaluation element is defined in detail. It is not expected that, in a specific evaluation, this level of detail will be achieved for many elements. The elements, as defined below, may therefore be thought of as a checklist. Many of the specific items in the checklist would normally entail expenditures of time and money above and beyond those available for model evaluation efforts, and are included in the hope that they may be available and also for the sake of completeness.

(U) The evaluation elements help define a model's domain of applicability and its limitations. Where applicable, recommendations will be made regarding model usage and improvements. A detailed description of the evaluation elements follows.

5.1 (U) Model Descriptiion

(U) The model description provides information in a variety of areas: (1) The purpose(s) of the model is set forth and is punctuated by providing examples of the model's outputs, including tabular and graphic results, as applicable. The extent to which outputs are under user control is identified. All output options are catalogued. (2) A list of input variables and their units. Inputs obtained from associated data bases or from internal routines or tables should be identified. This listing is to be functional and does not include a review of the physics upon which any input algorithms are based, such reviews being found in the "physics review" section. (3) A list of systems supported by the model. This list is to include the role performed by the model in the system and the stated purpose of the system. (4) Any limitations designed into the model through inherent limits of the physics, mathematics, environmental description, computer implementation, etc. These limitations, taken together, define the model's domain of applicability. Limitations are given in terms of parameters such as frequency, bandwidth, range, depth, angle, and time. Also included are limitations involving computer graphics or telemetry links. These limitations usually result from design decisions based upon the basic purpose of the model development effort or tradeoffs required by time, cost, and computer assets. (5) A list of extant model versions. These would include versions for research use and those adapted for system usage, land-based and shipboard versions, and those adapted for special computer requirements. Changes in input and output are noted, as are default values of various parameters.

5.2 (U) Physics and Mathematics

(U) The model is examined in terms of its physical and mathematical basis. The examination is performed by an independent expert in the appropriate field of modeling. In particular, the physics and mathematics are examined to define the model's domain of applicability through assumptions, approximations and the assignment of "nominal values" to various parameters. For propagation loss modeling, examples of the above are:

- (U) <u>Assumption:</u> Horizontally stratified medium, rendering the model incapable of correctly predicting propagation across thermal fronts or in areas of varying bathymetry.

- (U) <u>Approximation:</u> The merging of deep portions of historical temperature records to bathythermograph data, possibly causing errors in levels of the ranges at which features appear or even the prediction of features which do not exist in reality under certain environmental conditions.

- (U) <u>Nominal values:</u> In some models, rays radiating from the source up to a specified angle are accounted for in the propagation loss computations. The maximum value of this angle may be under user control or assigned a nominal value based on environmental expectations and running time requirements. In environments which exceed the expectation,

implied by the assigned nominal value, significant contributions to the total received level would be neglected.

(U) The reporting of the model's physics includes the basic foundations and approach and any unusual techniques and, particularly, any extensions to theory or unique capabilities otherwise unavailable. Examination of the model's physics and mathematics is to include consideration of environmental inputs, including theories and their implementation and appropriateness of environmental data base selection.

(U) It is assumed that mathematical notation will be employed. However, correspondence between mathematical symbology and variable names used by the program should be assured by a correspondence list.

5.3 (U) Run Time

(U) Run time of a model is a function of computer, number of points per prediction and input/output selections. Run times are given for a number of environmental/acoustic scenarios with appropriate identification of the above factors. Information on run time for each version of a model is desirable. Run time is to be divided into time required for computation and time for peripheral requirements such as plotting. Any tradeoffs between run time and accuracy should be described, including any relation to environmental and acoustic inputs.

5.4 (U) Core Storage

(U) Core storage will vary with model version, perhaps driven by available core and word length. Any efforts to reduce core storage requirements are to be identified such as overlays (independent subroutines being brought into addressable memory as needed and removed upon execution), memory mapping (addressing normally nonaddressable core by executive calls), disk memory swap (data brought from disk into memory a small amount at a time, calculations performed, results returned to disk, and the next data portion brought into core, etc.) and use of techniques such as interpolations in place of calculation.

5.5 (U) Complexity of Program Execution

(U) Complexity of program execution is directly related to the options available to a user. In a model to be used for research applications, complex and varied inputs may be required, special outputs at great levels of detail for diagnostic usage may be incorporated, and accuracy requirements are likely to be extremely stringent. Thus, for research-oriented models, input and output options must be broad with parameters affecting accuracy under user control implying great complexity of program execution. In contrast, a model intended for system usage or support, especially a shipboard application, should assign as many parameters as possible internally and be simple to execute. The simplicity of execution is achieved at the expense of an accurate, precise environmental description (which may be due to insufficient environmental sensing ability) or decreased accuracy of computations (often affordable in a broad system context).

(U) Complexity of program execution is revealed by providing (1) a sample program listing, (2) definition of all input and output parameters under user control, (3) default values or conditions assigned within the program, (4) restrictions on the values of arguments, (5) a detailed explanation of unusual parameters with guidance for their selection, and (6) reference to a user's guide.

5.6 (U) Ease of Effecting Program Alterations

(U) It is not uncommon that a program will satisfy most requirements for a given application but require some modifications before all criteria can be met. Modifications may range from

changing U.S. customary to metric units to altering the program to meet core storage or running time requirements. Other alterations include the assignment of default values to certain variables in going from research to system usage, the inclusion of archival data bases, and elimination of routines to calculate values of some needed variables that may be obtainable in situ, such changes typical of land-based models being adapted for shipboard use. Other significant alterations involve the forms of printed and graphic outputs, and most importantly, in many cases interfaces between the model and other models of the system. The ease of effecting program alterations is difficult to assess a priori. Of course, the more modularized a program, the easier it is to change one portion without affecting others. Hence, information on program architecture and flow can provide valuable clues as to the difficulty of effecting alterations. In addition to a flow chart, a program listing provides the most basic information, particularly when supported by documentation--both external to the program and internal in the form of comment cards. Lists of variables and their definitions are critical; choice of variable names consistent with common usage is very helpful in following a program's coding. Other information of extreme importance in effecting program alterations is the extent to which a program is tied into a computer executive system or other special equipment or programs.

5.7 (U) Ease of Implementation *(On a Different Computer)*

(U) Given that a program is running on one computer, we are often confronted with assessing the difficulty with which the program can be adapted to another computer. The most basic information helpful in this regard is a list of computers on which the program is running. Of course, if the computer of interest is on this list, the problem is likely solved. If not, other information can be extremely useful, such as the computer language, word length of the machines on which the program is presently running, special codes such as those necessary for plotting routines, and specialized library functions. Any tie-in to the executive system of a given computer is especially pertinent if implementation on another computer is to be performed.

(U) To assure correctness of implementation on a given computer, test cases that exercise all subroutines are necessary. A limited number of test cases would indicate correctness of implementation. All error returns should be documented as to location in the program and the nature of error indication.

5.8 (U) Cognizant Individual(s) and/or Organizational Element(s)

(U) In any specific application of a model, questions inevitably arise that are not answerable by reference to available documentation. Such questions often require lengthy discussions with those who have developed the model or have been responsible for its computer implementation and, in some cases, those who have developed the theory upon which the model is based. In some cases an organizational element is responsible for model configuration and maintenance. In any intended alteration of the model or desire to implement the model on a new computer, one of the aforementioned sources should be consulted.

5.9 (U) References

(U) A list of references provides valuable source material for detailed information about various aspects of model theory, implementation and usage. References worthy of special mention are: (1) a user's guide; (2) a response to SECNAVINST 3560.1, Tactical Digital Systems Documentation Standards, 8 August 1974; and (3) references to theories and numerical techniques employed by the model.

5.10 (U) By-Products

(U) Models often are capable of producing useful byproducts at little or no extra cost in running time or core storage. These byproducts may serve as diagnostic tools or may be valuable in their own right as exemplified by a ray diagram associated with a propagation loss model. Often, an output byproduct is an essential input for another model, such as the travel time of ray paths as a function of range being a byproduct of a propagation loss model (a required input for reverberation modeling.)

(U) The production of byproducts by a model may result in a single program taking the place of two or more programs. Often the production of byproducts exists in the form of exercisable options with minimal impact on the other factors influencing model selection.

5.11 (U) Special Features

(U) To achieve closer consonance with system features or for the sake of economics in running time or core storage, special features are often incorporated into a model. For example, a propagation loss model may have provisions for beam patterns to be imposed on a source and receiver consistent with a target radiation characteristic and own ship's sonar. Using interpolation in predicting results at several frequencies can substantially reduce running time below that required for calculation of results at each frequency.

5.12 (U) Accuracy Assessment *(Quantitative)*

(U) The quantitative accuracy assessment procedures compare the data generated by a model with a reference data set, be it measured data, the output of another model or data representing an exact solution. As shall be seen below the data are examined by two methods, the first insofar as possible isolates propagation modes (i.e., direct path, bottom interaction and convergence zone) identifying the range interval over which each given mode dominates, and then comparing the two data sets in each interval by generating statistics of their differences. One advantage of this procedure is that the range intervals are those of tactical interest; therefore, the success of a model in each of these regions is a useful way to delineate model performance. The second method utilizes figure of merit to compute detection ranges and to compare them. It is obvious that thus far we have restricted our attention to propagation loss models and it is only for this model type that quantitative accuracy assessment procedures have been defined. It is not difficult, however, to see parallels between propagation loss, ambient noise and reverberation. The independent variables of significance are range, angle, and time, respectively. Whereas propagation loss is delineated into modes of direct path, bottom interaction and convergence zone, ambient noise is differentiated into ship- and wind-generated noise and reverberation may be divided into surface, volume and bottom contributions. Although admittedly the analogies do not represent one-to-one correspondence, they should be of use in constructing quantitative accuracy assessment procedures for ambient noise and reverberation models.

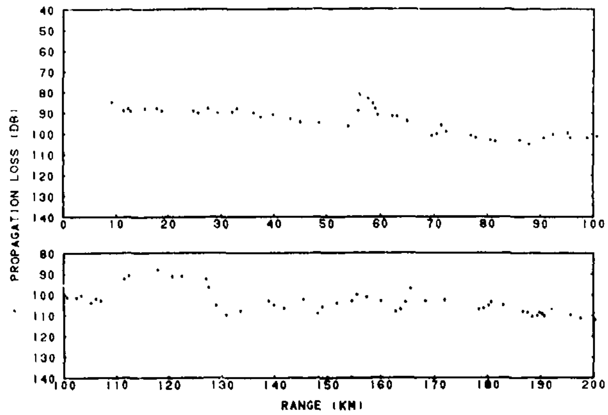
(U) The detailed accuracy assessment procedures for propagation loss models are as follows:

• (U) Step (1). Smooth the reference data set and the output of the model to be evaluated according to the following rules: smooth measured data if CW but not if 1/3-octave such as obtained from explosive sources; smooth model outputs of coherent phase addition were used but not if incoherent or semi-coherent phase addition was used. The purpose of this step is to remove rapid fluctuations, thereby putting data into a form where mean levels may be compared. This is a crucial point and bears further explanation. In a sense there are two sonar

equations, one for mean levels and one for the statistically fluctuating component. The sonar equation for mean levels is the one commonly referred to as "the sonar equation." An example of the other sonar equation is that the standard deviation of the signal excess is equal to the square root of the sum of the squares of the standard deviations of the factors of the mean level sonar equation. This particular form assumes independent Gaussian variables; other forms can be constructed that do not contain such restrictive assumptions. The point here is the necessity of breaking up the propagation loss into the two components and comparing the model output with a reference data set on the basis of those components. In the AMEC procedure only the mean levels are compared. They are obtained by means of data smoothing, specifically by the application of a 2 kilometer running average. The window size of 2 kilometers is consistent with sonar system integration times and typical target speeds (e.g., a target closing at approximately 12 knots and being detected on a sonar system with a five-minute integration time or a target traveling at a relative bearing of 60 degrees with respect to own ship at a speed of 24 knots, once again being detected on a system with five-minute integration time). Significantly larger averaging intervals smear some of the significant propagation loss features while smaller averaging intervals lead to the rapid fluctuations dominating the propagation loss field, and the desired mean level comparison is lost.

(U) Figure 1 gives a measured set of 1/3-octave data, and Figure 2 the output of a model that used coherent phase addition, and Figure 3, a smoothed version of the coherent model output obtained by performing running average with a 2 kilometer window.

• (U) Step (2). Subtract the model output from the reference data set (after both have been appropriately smoothed). Figure 4 is the result of such a



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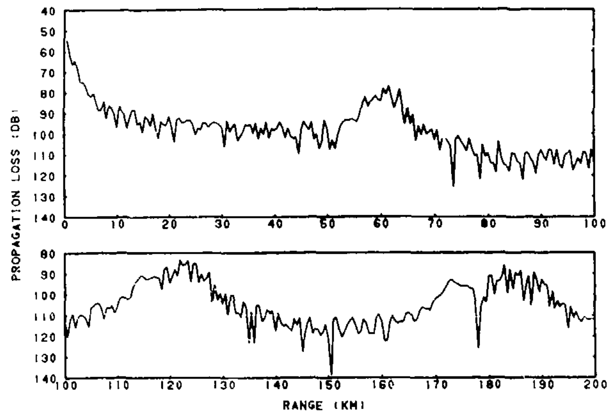
(U) Figure 1. PARKA Data: Source Depth-50 ft, Receiver-Depth 300 ft, Frequency-400 Hz



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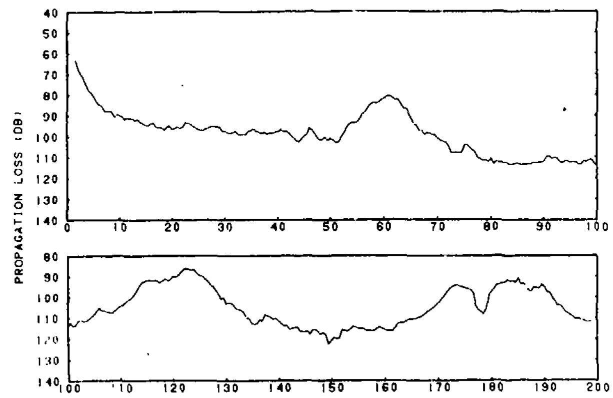
(U) Figure 2. RAYMODE X (Coherent): Source Depth-50 ft, Receiver Depth-300 ft, Frequency-400 Hz



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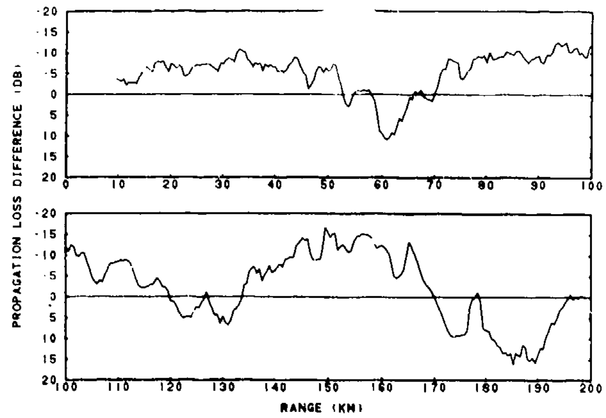
(U) Figure 3. RAYMODE X (Coherent): Source Depth-50 ft, Receiver Depth 300 ft, Frequency-400 Hz Sliding Averages of 5 Points (2.0 km)

subtraction, whereby the smoothed model ouput of Figure 3 was subtracted from the measured data set of Figure 1. After this step, the model under evaluation and the reference data set are inseperable. The aim here is not to set up the reference as representing absolute truth and, hence, all differences interpreted as errors in the model under evaluation. The aim, rather, is to observe problem areas and try to diagnose the cause(s) of large disparities, be they due to model under evaluation or reference (barring the case of closed form solutions). The difference curve and products derived therefrom must be interpreted with great care, least erroneous conclusions be drawn, a point which will be addressed in Step (6) and is supported by an example.

• (U) Step (3). Divide the difference curve into physically significant range intervals, if possible corresponding to direct path, bottom interaction and convergence zone modes of propagation. These range intervals are determined from the reference data set (possibly with the help of ray diagram). Figure 5 presents range intervals chosen from the reference data set. In the event that clearly identifiable features associated with propagation mode are not available in the reference data set, three choices are available: (a) do not divide the data into range intervals; (b) divide the data into quasi-arbitrary intervals that may be tactically useful (e.g., 5 km intervals out of 20 km, 20 km intervals out of 100 km, 50 km intervals thereafter); and (c) when clear features are available to which it is difficult to assign a single simple physical mechanism; nonetheless, use these features as the basis of forming range intervals.

• (U) Step (4). In each range interval calculate the mean μ and standard deviation σ of the differences. Table 1 gives μ's and σ's calculated from the curve of Figure 4 in the intervals of Figure 5. The need for both a mean value and a measure of spread (σ) is obvious upon considering the results for the region



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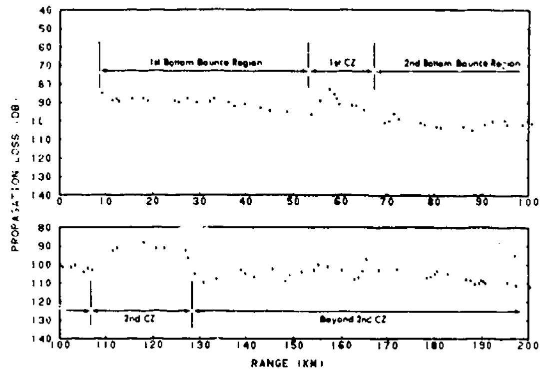
(U) Figure 4. Smoothed RAYMODE X (Coherent): Source Depth-50 ft, Receiver Depth-300 ft, Frequency-400 Hz Subtracted from Experimental Data, Source Depth-50 ft, Receiver Depth-300 ft, Frequency-400 Hz



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(U) Figure 5. PARKA Data: Source Depth-50 ft, Receiver Depth-300 ft, Frequency-400Hz

	μ	δ
First Bottom Bounce Region	-5.9	2.4
First Convergence Zone	1.0	3.1
Second Bottom Bounce Region	-5.8	6.2
Second Convergence Zone	-2.1	4.6
Beyond Second Conv. Zone	-1.4	9.5

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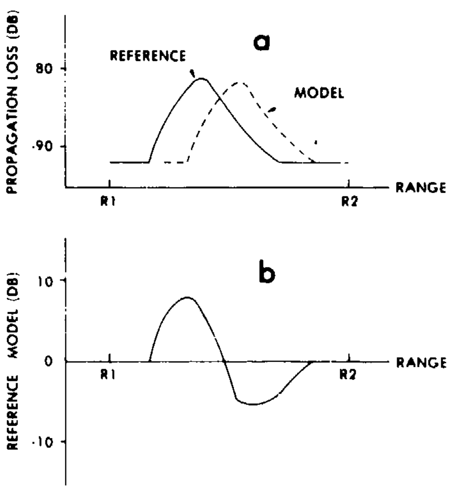
(U) Table 1. Means and standard deviations of differences between PARKA and smoothed RAYMODE X (Coherent) results in dB

"Beyond Second Convergence Zone" where observation of only the mean valve would lead to a conclusion of excellent agreement which consideration of the value for σ quickly dispels.

• (U) Step (5). Characterize convergence zones by giving range of onset, range extent, minimum transmission loss in decibels and shape (i.e., double vs. single lobe). The range of zone onset is given in terms of a selected transmission loss level in decibels as is the range extent of the zone.

• (U) Step (6). Analyze the results of Steps 1-5, attempting to diagnose the cause(s) of serious discrepancies between the model under evaluation and the reference data set. This step is essential, since the means and standard deviations can be quite misleading as the following example will illustrate. Consider the two propagation loss curves, representing convergence zones, of Figure 6a, one representing the model under evaluation, the other representing the reference. As can be seen the two curves are identical except for a displacement in range. Upon taking differences between the curves, as required by Step 2,



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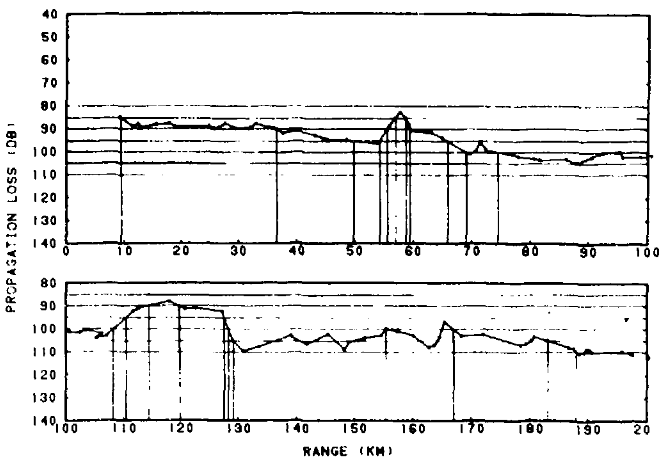
(U) Figure 6. Comparison of Propagation Loss vs. Range for Reference and Model Over Interval (R_1, R_2)

Figure 6b is obtained. Assuming the range interval (R1, R2) has been that chosen from Step 3, we then would proceed to calculate the mean μ and standard deviation σ. The result would be a mean value of zero and a very large standard deviation. Of course, an appropriate translation of one of the curves of Figure 6a would result in $\mu = \sigma = 0$. We see therefore that the large standard deviation can be somewhat misleading but is, in this example, a "red flag" inviting us to determine the cause of translation, such as the model lacking a curved earth correction or an erroneous value for the sound speed gradient in the deep portion of the profile. The essential lessons of the example are that the results of a single step such as Step 4 should not be viewed alone, but rather as a member of a hierarchy of results that begin with the basic curves and that Step 6 analysis is of paramount importance. We note in passing that, in the example given, Step 5 would have defined the problem giving a difference in convergence zone onset range for the two curves, but identical results for zone duration and peak level.

(U) The second quantitative method of accuracy assessment consists of presenting a table of detection range as a function of figure of merit. As in the earlier method, we apply the technique to smooth results and therefore begin with Step 1 which is to: smooth measured data if CW but not if 1/3-octave, such as obtained from explosive sources, and to smooth model output if coherent phase addition was used but not if incoherent or semi-coherent phase addition was used. The next procedure is to select figure of merit (FOM) values (for volumes II and III of this series the procedure was not automated, and 5 dB intervals were selected; for future propagation loss model evaluations, an automated procedure is available as described in Brunson (in prep.) for which tabular and graphical output is available with FOM intervals selectable to 1 dB intervals). Upon selection of FOM

values, the corresponding detection ranges (multiple range intervals for a single FOM value) are found as indicated in Figures 7 and 8 (which are the data sets of Figs. 1 and 3). As can be seen in Figure 7, linear interpolation is used when data points are widely spaced. (Note: For a given FOM, for example, FOM=90 dB, we see that in Fig. 7 the transmission loss (TL) is always less than 90 dB until a range of 36.5 km. The TL curve remains below 90 dB until the first convergence zone. Between 55.5 and 59.0 km, the TL is greater than 90 dB.



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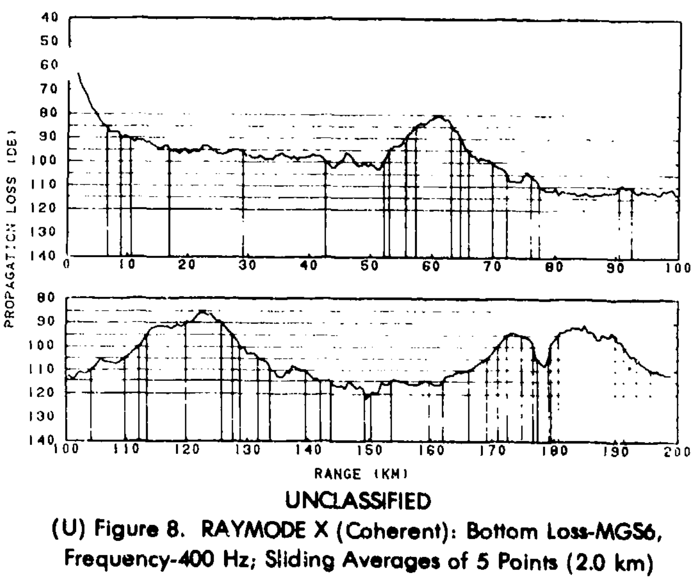
(U) Figure 7. Experimental Data: Source Depth-50 ft, Receiver Depth-300 ft, Frequency-400 Hz



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(U) Figure 8. RAYMODE X (Coherent): Bottom Loss-MGS6, Frequency-400 Hz; Sliding Averages of 5 Points (2.0 km)

This occurs again in the second convergence zone between 114.5 and 120.0 km.) These results are finally tabulated as exemplified by Table 2. The contents of the table are not purely numeric and verbal descriptions are used when warranted. (Note: When a TL curve oscillates about a given FOM over some stated range interval, the concept of zonal detection coverage (ZDC) is introduced, ZDC is defined to be the percentage of the range interval over which the FOM is less than the TL.)

6.0 (U) Data for Accuracy Assessment - An Environmental/Acoustic Matrix

(U) The assessment of model accuracy is obtained by comparing the model's output with three basic data types: (1) experimental acoustic results, (2) output of a reference model and (3) closed form solutions.

(U) The experimental acoustic data is supported by environmental data sufficient for model input requirements. Model results are compared with experimental acoustic data using standard comparison criteria. The totality of the experimental data sets for evaluating a given model type (e.g., propagation loss models with range independent inputs) cannot and is not expected to be complete, either acoustically or environmentally. The sets are, rather, taken together, intended to provide a broad range of representative conditions. Thus, for example, propagation loss data sets should contain results from many ocean basins, representing various sound speed profile types including some with and without depth excess, a surface duct, those having shallow and deep sound channels, subsurface channels and double channels. Bottom types and bottom depths should be varied. A range of frequencies covering surveillance, tactical sonar and weapons sonars should be represented, as should various source/ receiver depth combinations. Finally, the various propagation modes of surface duct, bottom bounce, and convergence zone should be represented. Obviously,

(U) Table 2. Detection Range as a function of Figure of Merit (FOM) for PARKA experimental data (P) and RAYMODE X smooth coherent (RXC) prediction (all ranges in kilometers)

				CZ 1			CZ 2			CZ 3			
										Lobe 1		Lobe 2	
Data Set	FOM (dB)	R_c[1]		Start	End		Start	End		Start	End	Start	End
P	85	9		58	59.5								
RXC	85	7		57.5	63.5								
P	90	36.5		55.5	59		114.5	120					
RXC	90	10		56	65		120	126					
P	95	50		54	66		110.5	127					
RXC	95	17	ZDC[2] 50% 17–29 km	53	66		113.5	127.5		172.5	175	181	190
P	100	69			69	ZDC 15% 69–108 km	108	128	3 km cov. at 165 km				
RXC	100	42.5		52.	69.5		112	129		171	176.5	179.5	191.5
P	105	129				2 km cov. at 75 km		129	ZDC 60% 124–183 km				
RXC	105	72			72		110	132		169	177.5	179	193.5
P	110	188				2 km cov. at 91 km							
RXC	110	77.5			77.5		104.5	134		166.5			196
P	115	>200											
RXC	115	143							ZDC 40% 154–160 km	162			

1 R_c = Range to which detection coverage is continuous.

2 ZDC = Zone Detection Coverage (i.e., detection coverage is zonal in nature over the range interval from 17 to 29 km; in this interval the FOM level of 95 dB is exceeded 50% of the time).

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(U) *Table 3. Experimental data for use in accuracy assessment of range independent propagation loss models*

DATA SETS	LOCATION	PROPAGATION MODE	Zs/Zr	FREQUENCY ≤ 1kHz	FREQUENCY $1 \leq F \leq 5$kHz
HAYES-MURPHY	MEDITERRANEAN	BB	S/S	√	
PARKA	PACIFIC	BB/CZ	S/S	√	
SUDS	PACIFIC	SD	S/S	√	√
GULF OF ALASKA	GULF OF ALASKA	BB MULTI CZ	D, S/S		√
BEARING STAKE	INDIAN OCEAN	BB	S/S	√	
LORAD	PACIFIC	MULTI CZ	S/S	√	√
FASOR	PACIFIC/INDIAN	CZ/SD BB, SHALLOW	S/S		√
JOAST	MEDITERRANEAN	CZ	S/S		√
JAGUAR-BRASIL	S. ATLANTIC	SHALLOW	S/S	√	√
ATOE	W. ATLANTIC	Sound. Channel	SCA/SCH		√
IOMEDEX	IONIAN BASIN, MED	BB	S/S, D		

BB = BOTTOM BOUNCE

SD = SURFACE DUCT

CZ = CONVERGENCE ZONE

SCA = SOUND CHANNEL AXIS

S: ≤ 1 KFT

D: >1 KFT

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complete coverage of these various parameters implies an environmental/acoustic matrix of enormous size. Only for a few elements of this matrix are experimental data available. This necessitates the use of environmental acoustic scenarios unsupported with experimental propagation loss data. The environmental acoustic scenarios unsupported by experimental data are used by comparing results from the model under evaluation with those of a reference model. These comparisons are used in a diagnostic sense to identify model limitations and failures. (In this context, both the model under evaluation and the reference model are considered suspect when discrepancies are found.) Under the auspices of AMEC, twelve sets of data have been identified, examined, and deemed suitable for range independent propagation loss model evaluation (i.e., satisfied criteria of range independence, contained sufficient data density, and have adequate supporting environmental data). These sets are described in Martin (1981) and are designated as SUDS, GULF OF ALASKA, FASOR, LORAD, PARKA II, HAYS-MURPHY, JAGUAR-BRASIL, BEARING STAKE, JOAST, ATOE, and IOMEDEX. Table 3 summarizes some basic characteristics of eight of these sets, which indicates that they are representative of the matrix giving the totality of environmental/acoustic scenarios. We note that each experimental data set can consist of many data records corresponding to different frequencies, tow tracks, source/receiver depth combinations, etc. For the evaluation of a specific model, a subset of the available data records would be selected for accuracy assessment. The choice of this subset would be determined by the model's intended domain of applicability. Tables 4-14 give synopses of important features for each data set of the pool for use in range independent propagation loss model evaluation. The experimental data sets herein described are not to be though of as a final selection but rather those examined and summarized to date. Data sets identified for examination to determine their applicability to range dependent propagation loss model evaluation are ROUGH START, SQUARE DEAL, NORLANT 72, ATOE, PARKA II, TRANSLANT I, NEAT II, SUDS, and BEARING STAKE.

(U) It is often desired to assess the accuracy of a model for an environmental scenario unsupported by acoustic experimental data. In such cases the model results, as mentioned above, are to be compared with the outputs of one or more reference models. A reference model is not to be considered a "standard." An attempt is made, however, to choose a reference model, the physical and mathematical basis of which is more rigorous than that of the model to be evaluated. In comparing results from two models it is usually essential that the models be run with identical data bases and that the data bases be separated from the models. For example, in two propagation loss models, the bottom loss may be a subroutine of each model. For valid comparison of propagation loss results the bottom losses must be identical (which may require alteration of one or both models). Here, a difficult practical issue arises. In its application by a user, a model is often adopted <u>with</u> a data base, exemplified by bottom loss. The potential user would like to see the model/data base package evaluated. This is accomplished by means of <u>factor isolation</u> whereby for a given scenario only a single factor, such as bottom loss, is varied. The scenario is chosen so that the factor of interest is dominant. Thus, the model may be run with infinite bottom loss, a bottom loss table in fleet usage, bottom loss determined from a model containing subbottom structure, etc. The effect of the factor is thereby assessed for the model being evaluated.

(U) Sometimes in comparing two models, the use of identical data bases is impossible, but some equivalence must be achieved. To illustrate, consider two ambient noise models (horizontally directional at low frequency). One, the

(U) Table 4. SUDS I Parameters

Appendix Station Run	A 1 3,4	B 1 5,6	C 3 2	D 3 3	E 1 1,2	F 4 1	G 4 3	H 4 4
Layer depth (m)	68	79	6	11	20	17	0	10
Depressed channel axis (m)	-	-	20	20	200	-	0	-
Max. sound speed depth (m)	68	79	90	79	250	17	0	10
Axis depth (m)	900	900	700	700	900	700	700	700
Source depths (m)	1.0, 0.4	5.0, 3.5	42	42	41	43, 46	43	43
Receiver depths (m)	4,17,43, 72,112	4,17,43, 72,112	6,37,73, 119,182	6,34,69, 112,173	6,24,59, 98,148	6,36,73, 118,181	6,36,72, 117,180	6,36,72, 117,180
Frequencies (kHz)	4.5, 42	4.5, 42	1.5, 2.5	0.4, 1.0	1.5, 2.5	3.5, 5.0	1.5, 2.5	1.5, 2.5
Min. range (kyd)	2.2	0.1	3.9	0.1	0.5	0.1	2.3	2.6
Max. range (kyd)	26.6	27.5	31.4	34.6	27.1	33.3	35.1	33.4

Bottom depth - only non-bottom reflected signals were processed. Model should assume infinite bottom loss.

Navigation - Radio tones to measure acoustic travel times with accuracy ±15 m.

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(U) Table 5. Gulf of Alaska parameters

Run Number	140	143	124	108	107	112A	112B
Frequency (kHz)	1.5	1.5	1.5	2.5	2.5	2.5	2.5
Source Depth (m)	30.5	30.5	30.5	1067	1067	305	305
Receiver Depths (m)	15,30.5 90,229,305	Same	Same	Same	Same	Same	Same
Minimum Range (kyd)	40.6	9.5	3.1	2.8	32.9	16.6	2.1
Maximum Range (kyd)	69.3	58	12.1	30.9	73.5	63.9	20.3
Bottom Depth (m) S. Speed (m/s)	4078 1525.4	4042 1524.7	4042 1524.7	4060 15[illegible].0	4060 1525.0	4060 1525.0	4042 1524.7
Layer Depth (m) S. Speed (m/s)	10 1476.7	10 1476.8	10 1476.5	0 1477.6	10 1476.6	10 1479.1	10 1479.2
S. Speed Minima (m/s) Depth (m)	1461.9 75	1462.5 90	1461.9 75	1462.5 85	1462.5 85	1462.0 75	1461.9 75
NAVDAB EXP. 9 RUN NO.	1-5	11-15	31-35	6-10	16-20	21-25	26-30
NAVIGATION - Range determined by clock differences times sound speed: Accuracy 100 yds							

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(U) Table 6. Parameters for FASOR 'ations

FASOR Station	FIG	REDWOOD	OAK	THORN	INDIA	JULIETT
NAVDAB: Exp.	2	2	2	2	8	8
Station	6	18	15	20	10	11
Run	3	3	1,2	1,2	1,2	1,2
Frequency (kHz)	1.5	1.5	1.5	1.5	1.5	1.5
Source Depth (m)	6.1	6.1	23	23	23	23
Receiver Depth (m)	37	37	37	37	37	37
Min. Range (kyds)	6.5	1.0	13.8	13.4	25	14.7
Max. Range (kyds)	57.1	39.0	47.5	37.0	47.9	57.0
Layer Depth (m)	0	19	30	55	50	75
Axis Depth (m)	NA	1200	NA	NA	NA	NA
Wind Speed (knots)	18	8	6-12	5-6	14-15	8-9
Wave Height (ft)	4	1	4	1	4	2
Swell Height (ft)	6	4	8	3-5	6	3
Bottom Depth (m)	7648	3282	120	104	50	124

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(U) Table 7. Range, depth, and frequency parameters for the LORAD/HAWAII data set

NAVDAB Run No. Data Set Figure	1 1 4	1 2 4	2 1 5	2 2 5	3 1 6	3 2 6	4 1 7	4 2 7	5 1 8	6 1 –	6 2 –	6 3 –
Source Depth (ft)	50	50	180	180	50	50	180,* 155	180,* 155	110	50	50	50
Receiver Depths (ft)	1000	100	1000	100	1000	100	1000	100	100	1000	300	100
Frequency (kHz)	0.530	0.530	1.03	1.03	0.53	0.53	1.03	1.03	1.03	0.53	0.53	0.53
Min. Rang (kyd)	0.38	0.74	0.46	0.44	3.04	1.96	1.92	1.88	89.0	45.0	[illegible]	45.0
Max. Range (kyd)	9.14	9.2	9.0	20.5	76.2	79.0	22.0	21.9	100.9	143.0	142.8	143.0
Layer Depth	122	122	122	122	Approximately 110 feet							
Sound Axis	The axis of minimum sound speed is about 2500 feet											
Bottom Depth	Depth to bottom is assumed constant at 3100 fm (5670 m).											
Navigation	Range was established by a radio link between source and receiving ships.											
Comment	– group runs 3,6,8,10,12,14 and 16 for 530 Hz data – group runs 7,9,11,13,15 and 17 for 1030 Hz data – treat runs 1,2,4 and 5 separately											

*Source depth was 155 ft from 9 to 22 kyds.

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(U) Table 8. PARKA IIA parameters

Comment: PARKA Events 9-2 and 9-3 are the only ones with nearly range independent environments over the entire tracks. These events resulted in nearly identical propagation loss level vs. range and therefore only Event 9-2 is recommended for evaluation

Event #	9-2
Source type	3 lb. TNT blocks
Detonation depth control	Fuse cut to length
Source depths (ft)	60 and 500
Receiver depths (ft)	300/2500/10,800
Analysis frequency (Hz)	25/50/100/180/400
Analysis bandwidth/type	1/3 octave/total energy
Min range (nm)	2
Max range (nm)	500
Surface sound speed (ft/sec)	5022.16
Layer depth (ft)/sound speed (ft/sec)	262.5/5026.49
Sound axis depth (ft)/sound speed (ft/sec)	3280.8/4857.19
Bottom depth (ft)	18,600
Navigation	Radio tone 0.1 nm accuracy

Data location - NUSC digital tape stored with others at Federal Records Center, Waltham, MA. Rec. Group #181, Accession #75-A-342 FRC Box #425582 or 425583. Reel with label P2RR3 (Box 5 of Aug 74 shipment to Waltham), NUSC point-of-contact - Stan Jackson.

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(U) Table 9. HAYS-MURPHY parameters

Exercise:	Mediterranean Sound Transmission (1968)
Event:	ST. MARGARETS
Source Type:	1 lb. TNT
Source Depths:	80 and 325 ft
Receiver Depths:	350, 450 and 1000 ft
Acoustic Analysis:	1/3 octave total energy
Frequencies:	35, 67.5, 100 and 200 Hz
Data Density:	80 ft source, 3 shots per nm 350 ft source, 1 shot per 10 nm
Range over which Environment is Range Independent:	0–240 nm
Water Depth:	1500 fathoms max (2750 m) 1420 fathoms min (2600 m)
Environmental Data:	Sound velocity profiles and water depth vs. range
Navigation:	Not addressed in report as such
Range Determination:	Radio link time difference
Range Accuracy:	Less than 1.5% of range -- probably better than 0.5% of range
Data Location:	Each plotted value tabulated vs. range in Reference (1)
Comments:	(1) Source level accuracy is 3 dB or better (2) Depth excess is 1500 m or more. Bottom reflected energy may dominate below 67.5 Hz but probably contribute little above 100 Hz.

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(U) Table 10. JAGUAR exercise parameters summary

	Shot Event	1.6 kHz Tow	2.6 kHz Tow
Source type	SUS 1.8#TNT+	Scroll 190 dB// PA	Scroll 190 dB//1 PA
Source depth (m)	18	18	18
Receiver depths (m)	20, 40	20, 40	20, 40
Source freq (kHz)	0.1 to 5.0	1.6	2.6
Analysis bandwidth	1/3 oct	0.12 Hz	0.12 Hz
Min range (km)	2	0.5	1.5
Max range (km)	52	40	43
Surface sound speed (m/s)	1 532	1 532	1 532
Layer depth (m)	40*	40	40

+Source levels from ref 3 (Gaspin and Shuler).

*Typical sound speed profile is profile #3 of Figure 5.

Bottom depth: 58 m

Navigation: acoustic travel time and radar ranges (1% agreement) for shots. Radar ranges for CW events. Accuracy 50 m.

Processing shots: Total energy in 1/3 octave bands.
CW: Total energy in 0.12 Hz bands.

Data location - NUSC/New London, Mr. John Chester

Surface conditions - Wind speed 10 kn, sea state 1, swell period 12 sec.

Environmental data - XBT salinity vs. depth converted to sound speed
Bottom grab samples for sediment analysis
Sediment layer average sound speeds
Climatology
Bathymetry

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(U) Table 11. BEARING STAKE parameters, Site 1B, Bottom Mounted Array

EVENT	S1	S1	S1	S1	S1	S1	S1	S1	P1	P1	P1	P4	P4	P4
Seq No.**	46-47	48	49-50	51	52-53	54	55-56	57	133	134	135	136	137	138
Fig.	-	-	15a,b	17a	-	-	16a,b	17b	18a	18b	18c	-	19a	19b
Freq (Hz)	20	20	50	50	140	140	300	300	25	140	290	39	140	290
Source Depths (m)	244, 91	18	244 91	18	244 91	18	244 91	18	91	18	18	102	18	18
Rec Depths (m)	3350*	*	*	*	*	*	*	3350*	3350*	*	*	*	*	3350*
Min Range (km)	1.9	11.3	1.9	11.3	1.9	11.3	1.9	11.3	2.0	2.0	2.0	4.0	4.0	4.0
Max Range (km)	292	280	292	280	292	280	292	270	296	296	296	130	130	130
Layer Depth (m)	75							75	10	10	10	10	10	10
Depth of Min Sound Speed (m)	1676							1676	1725	1725	1725	1725	1725	1725
Bottom Depth (m)	3350 meters													3350

**Refer to the element table correspondence to the taped runs.

*Receiving hydrophones on the bottom. CONFIDENTIAL

(U) Table 11 (continued). Parameters for Bearing Stake exercise, Site 1B, VAC

EVENT	P4	P4	P4	P4	P4	P4	P1	P1	P1	P1	P1	P1
Seq No.	131-122	123-124	125-126	127-128	129-130	131-132	109-110	111-112	113-114	115-116	117-118	119-120
Fig.	24	25	-	-	-	-	-	-	23a,b	-	-	-
Freq (Hz)	39	39	140	140	290	290	25	25	140	140	290	290
Source Depths (m)	102	102	18	18	18	18	91	91	18	18	18	18
Rec Depths (m)	496, 1685	3321, 3351	496, 1685	3321, 3351	496, 1685	3321, 3351	496, 1685	3321, 3351	496, 1685	3321, 3351	496, 1685	3321, 3351
Min Range (km)	12.0	12.0	12.0	12.0	12.0	12.0	6.0	6.0	6.0	12.0	12.0	12.0
Max Range (km)	122.0	122.0	122	122	122	122	288	288	286	288	288	280
Layer Depth (m)	10						10	10	10	10	10	10
Depth of Min Sound Speed (m)	1715						1725	1725	1725	1725	1725	1725
Bottom Depth (m)	Depth to bottom is assumed constant at 3350 m.											

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(U) Table 11 (continued). Parameters for BEARING STAKE exercise, Site 1B, VAC

EVENT	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Seq No.	1–3	4–6	7–9	10–12	13–15	16–18	19–21	22–24	25–27	28–30	31–33	34–36	37–39	40–42	43–45
Fig.	–	20a	20b	20c	–	–	21a	–	21b	–	–	22	–	–	–
Freq (Hz)	20	50	125	315	500	20	50	125	315	500	20	50	125	315	500
Source Depths (m)	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244	18, 91 244
Rec Depths (m)	496	496	496	496	496	1685	1685	1685	1685	1685	3321	3321	3321	3321	3321
Min Range (km)	8	8	6	6	6	8	8	8	6	6	8	8	6	6	6
Max Range (km)	284	284	288	288	284	284	284	284	288	288	288	288	284	284	284
Layer Depth (m)	A layer depth of 75 m was observed for EVENT S1														
Depth of Min Sound Speed (m)	1676														1676
Bottom Depth (m)	Depth to bottom is assumed to be constant at 3353 m.														

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(U) Table 11 (continued). BEARING STAKE parameters, Site 4, VAC

EVENT	P1	P1	P1	P1	P1	P1
Seq No.	97-98	99-100	101-102	103-104	105-106	107-108
Fig.	0	29,30	31	-	-	-
Freq (Hz)	25	25	140	140	290	290
Source Depths (m)	91	91	18	18	18	18
Rec Depths (m)	400, 1916	5076, 5106	400, 1916	5076, 5106	400, 1916	5076, 5106
Min Range (km)	10	10	6	6	6	6
Max Range (km)	308	308	308	308	305	285
Layer Depth (m)	0	0	0	0	0	0
Depth of Min Sound Speed (m)	1785					1785
Bottom Depth (m)	Bottom depth is approximately 5105 m to about 295 km along the track.					

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(U) Table 12a. JOAST III parameters

STATION	3	5
RUNS	1-12	1-4
LAYER DEPTH (ft)	80 ft nominal	420 ft nominal
MAX SOUND SPEED DEPTH (ft)	8500	8200
AXIS DEPTH (ft)	260	1300
DEEP SOUND CHANNEL DEPTH (ft)	6600	6200
SOUND VELOCITY PROFILE	See Fig 3-6 and Tables 3-7	See Fig 3-7
SOURCE DEPTHS (ft)	20	20
RECEIVER DEPTHS (ft)	60, 85, 110, 135, 160, 185, 210, 235, 260, 285, 310, 335, 360, 385, 410, 435, 460, 485, 510, 535	Same as for Station 3
FREQUENCY (kHz)	3.050-3.150, 3,250 3.350-3.450, 3,550 3.650-3.750, 3,850	Same as for Station 3
DATA DENSITY	14 values/nm in CZ	14 values/nm in CZ
MIN RANGE (kyd)	36	40
MAX RANGE (kyd)	53	55
BOT OM DEPTH (ft)	8500 plus	8200 plus
	Model should assume infinite bottom loss since only refracted paths are important.	
NAVIGATION	Radio Tone – measure acoustical travel time, range accuracy – within 100 yds.	
DATA LOCATION	NAVDAB	

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Table 12b. JOAST IV parameters

STATION	9	7
RUNS	D2C and D2B	B1B and B1C
FREQUENCIES (kHz)	0.025 - 1.0, 1/3 octave	0.025 - 1.0, 1/3 octave
LAYER DEPTH (ft)	100-140	110 nominal
MAX SOUND SPEED DEPTH (ft)	9000	1200
AXIS DEPTH (ft)	450	520
DEEP SOUND CHANNEL DEPTH (ft)	4750	5500
SOURCE DEPTHS (ft)	800, 300	300, 800
RECEIVER DEPTHS (ft)	60, 350, 800	60, 350, 800
MIN RANGE (nmi)	5	5
MAX RANGE (nmi)	300	90
BOTTOM DEPTH	8400	8400
	Model should use bottom depth of 8400 ft, bottom loss from archival files.	
NAVIGATION	Radio Tone - acoustic travel time average speed, range update, radar, dead reckoning plots - range errors not given.	
DATA LOCATION	NAVDAB	

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(U) Table 13. ATOE parameter depressed sound channel measurement

Layer Depth (m)	Depress Channel Axis (m)	Channel Depth (m)	Bottom Depth (m)	Source Depth (m)	Rev. Depth (m)	Frequencies (kHz)	Min Range (nmi)	Max Range (nmi)
150	1205	3658	4939*	1220	1265, 1417	.025,.05,.1, .2,.4,.8,1.6	25	400

*Average Value min 4390, max 5487. Since the source is omnidirectional and the received signal is integrated over all paths, bottom effects are initially effective in range. (See also, factors which may effect model comparison.)

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(U) Table 14. Parameters for the IOMEDEX data set

Figure 6	A	B	C	D	E	F
Frequency (Hz)	125	125	125	125	125	125
Source Depth (m)	152	152	152	152	152	152
Receiver Depth (m)	137	613	1113	1116	2377	2650
Min Range (nm)	8	8	8	8	8	8
Max Range (nm)	128	135	138	135	120	120
Layer Depth (m)	42	42	42	42	42	42
Sound Axis (m)	The axis of min sound speed is about 130 m					
Critical Depth	The mean critical depth is 1000 m					
Bottom Depth	Assumed constant at 3000 m					
Navigation	Range accuracy was ± 0.2 nm (see Reference 2)					
Data Location	Data can be accessed through the "LRAPP Acoustic Data Bank" by request to NORDA Code 520 SEAS Project, NSTL Station, MS 39529					

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model to be evaluated, uses a statistical ship distribution. The other, the reference model, is more detailed and represents the ships as point sources. In comparing these models, it is essential that the point model have ship statistics equivalent to those of the model which uses a statistical ship distribution.

(U) The use of a reference model is indicated in the following situations: (1) no experimental data is available for a scenario for which the model is intended, (2) comparison of the model under evaluation with experimental data has resulted in unexplainable discrepancies, (3) a specific feature of the model requires evaluation as indicated by an examination of the physics and mathematics of the model, and (4) the sensitivity of the model to a given factor (e.g., bottom loss) is to be determined. For range independent propagation loss models, a set of environmental scenarios is contained in Hammond and Rubisch (1976). A map giving the geographic coverage represented by the Hammond and Rubisch scenarios is given in Figure 9. A typical set of parameters is given in Table 15. These encompass bottom loss, bottom parameters and sound speed profile.

(U) Closed form solutions are important benchmarks that must be achieved by models. A model's inability to match these solutions is an indicator of errors in computer coding, overly simplifying assumptions or approximations, or improper selection of parameters.

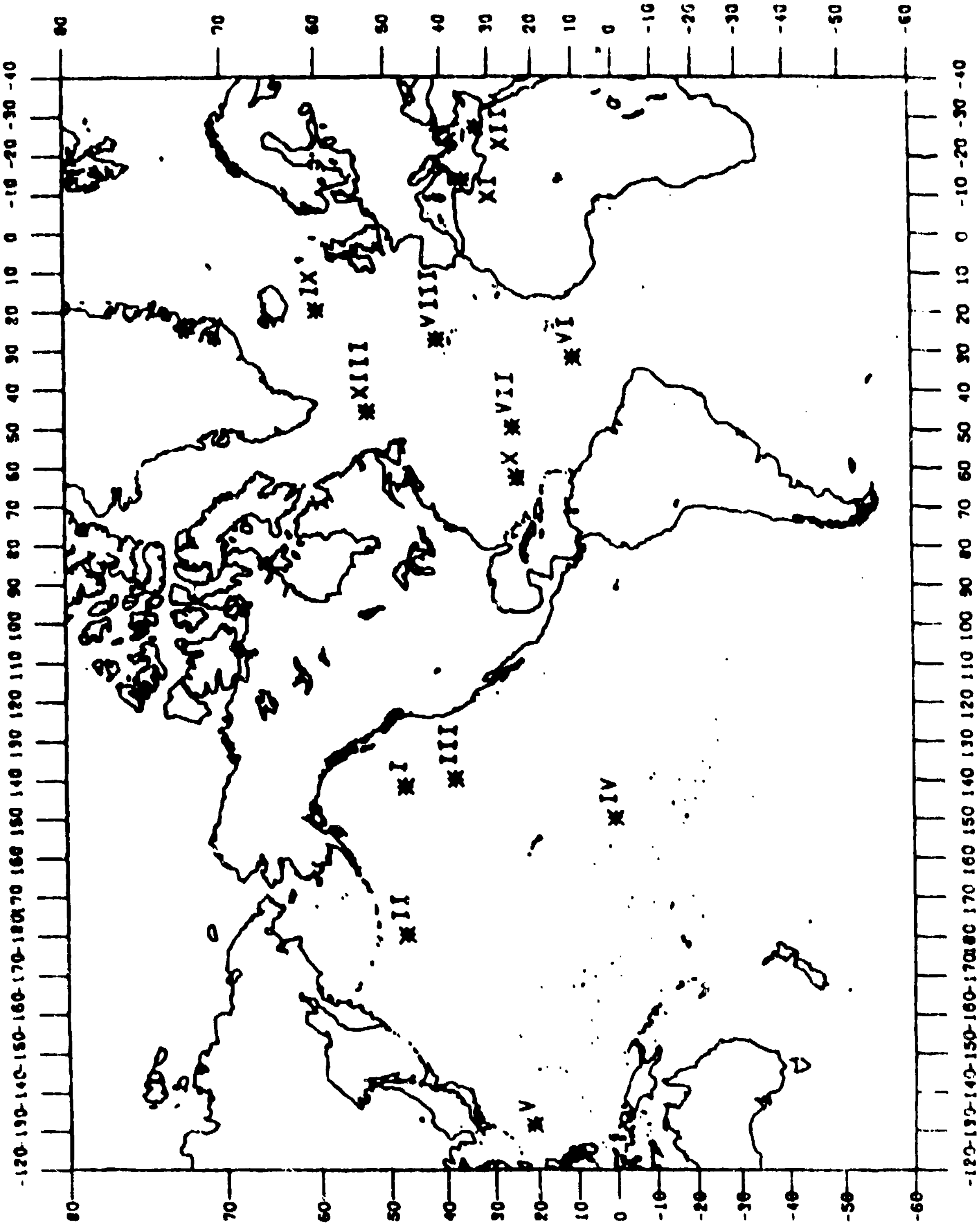
7.0 (U) Summary

(U) The Acoustic Model Evaluation Committee has developed a methodology for the evaluation of propagation loss models using both range independent and range dependent environmental inputs. Most, if not all, of the methodology is applicable to ambient noise and reverberation models. For propagation loss models, environmental acoustic data sets have been reviewed for their appropriateness to model evaluation from the viewpoint of quality, completeness of environmental data for model input, factor isolation (e.g., convergence zone propagation), geographic coverage, and frequency coverage. The salient features of these data sets have been summarized and reported for range independent propagation loss (Martin, 1981) and for range dependent propagation loss (Martin, in prep.). Subsets of the range independent sets have been acquired on digital tape, examined for obviously bad data points, edited and, finally, put on a tape that constitutes one part of a portable test package.

(U) The remaining two parts of the portable test package are a Model Information Form for the model developer to complete and a computer program, MCPRO, for the quantitative comparison of two data sets (Sussman and Oberlander, 1979). The Model Information Form is applicable to both range independent and range dependent propagation loss models and, with minor additions and alterations, can be used for ambient noise and reverberation model evaluation. With the completion of the portable test package for range independent propagation loss models, these models can be evaluated in 10-12 months. This does not, however, mean that this aspect of model evaluation is either perfect or complete. The methodology has been and remains in an evolutionary state. Improvements in the methodology are indicated in at least two areas:

- (U) Model Sensitivity. To what degree is the output affected by a change in input over a realistic span of values? For example, as bottom loss type is changed from 1 to 9, does the output show a monotonic change of values and is there also a change in the basic nature of the output, such as the emergence of convergence zones?

- (U) Fluctuations. The accuracy assessment procedure used by AMEC is based on mean levels (i.e., the fluctuating component is removed). However, the fluctuating component of propagation loss is



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(U) Figure 9. Areas I to XIII Geographic Locations

(U) Table 15. Area X Nares

(C) 1. Location: 24°N, 63°W

(U) 2. Submarine Province: Nares Abyssal Plain

(U) 3. Water Depth: About 3100 fathoms (5890 m) throughout the area.

(U) 4. Sediment Type: Pelagic red clay with layers of acoustic reflecting material, typically limestone and cherts.

(U) 5. Sediment Thickness: 200 - 300 m.

(U) 6. Bottom Loss: Low to intermediate

(U) 7. Sound Speed Profile:

	Depth Excess	MLD	MVD
Winter	1600 m	50 m	1370 m
Summer	1240 m	30 m	1370 m

(U) 8. Ship Density:

a. Total Ships/10° sq = 77
b. Ships/sq mile = 2.36×10^{-4}
c. Percent Fishing Vessels = 15%

(U) 9. Ambient Noise level (uPa) as a function of frequency and depth:

	50	100	160	315	500	630	1000
90 ft (27.4 m)	86.0	78.5	73.1	66.4	65.3	64.2	61.9
300 ft (91.4 m)	85.2	80.5	74.9	68.7	61.3	54.6	47.6
1000 ft (304.8 m)	79.1	73.1	68.8	62.7	62.4	60.9	58.6

The levels at 500, 630, and 1000 Hz vary with the conditions of the seas. The levels were measured at 300 ft in a sea state 1 and the 90 ft and 1000 ft in a sea state 2.

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(U) Table 15 (continued). Area X (24° N, 63' W).
Bottom Loss (dB) as a Function of Grazing Angle and Frequency

GRAZING ANGLE (DEGREES)	50	100	160	315	600	630	1000
0	0.0	0.0	0.5	0.5	1.0	1.5	2.0
5	0.5	0.8	1.3	1.8	2.5	3.5	4.5
10	1.0	1.5	2.0	3.0	4.0	5.5	7.0
15	1.7	2.3	2.8	3.6	4.5	5.8	7.2
20	2.5	3.0	2.5	4.3	5.0	6.0	7.4
25	3.3	3.8	4.3	4.9	5.5	6.5	7.6
30	4.2	4.5	5.0	5.5	6.0	6.8	7.8
35	5.0	5.0	5.5	6.0	6.5	7.5	8.0
40	5.3	5.0	6.0	6.5	7.0	7.8	8.2
45	6.0	5.0	6.5	7.0	7.5	8.0	8.4
50	6.0	5.0	6.5	7.0	7.5	8.0	8.5
55	6.0	5.0	6.5	7.0	7.5	8.0	8.5
60	6.0	5.0	6.5	7.0	7.5	8.0	8.5
65	6.0	5.0	6.5	7.0	7.5	8.0	8.5
70	6.0	5.0	6.5	7.0	7.5	8.0	8.5
75	6.0	5.0	6.5	7.0	7.5	8.0	8.5
80	6.0	5.0	6.5	7.0	7.5	8.0	8.5
85	6.0	5.0	6.5	7.0	7.5	8.0	8.5
90	6.0	5.0	6.5	7.0	7.5	8.0	8.5

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(U) Table 15 (continued). Area X (24° N, 63' W). Sound Speed Profile

WINTER DEPTH (M)	WINTER SPEED (M/SEC)	SUMMER DEPTH (M)	SUMMER SPEED (M/SEC)
0	1534.1	0	1544.2
46	1535.0	30	1544.8
76	1533.4	50	1542.7
244	1521.[illegible]	75	1538.6
427	1519.9	100	1532.8
549	1514.8	125	1534.0
792	1500.2	130	1531.9
975	1494.1	200	1527.7
1097	1492.9	250	1525.0
1372	1492.3	300	1523.2
1676	1495.0	400	1521.6
2438	1504.5	500	1517.4
3048	1513.0	549	1514.8
4267	1532.2	792	1500.2
5486	1554.2	975	1494.1
5890	1561.4	1097	1492.9
		1377	1492.3
		1676	1495.0
		2438	1504.5
		3048	1513.0
		4267	1532.2
		5486	1554.2
		5890	1561.4

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also important for the prediction of sonar system performance. One typical fluctuation measure is the standard deviation of the signal excess which is partially based on the standard deviation of the propagation loss. Of still more basic interest is the probability density function of the transmission loss (Urick, 1975).

(U) With the additions listed above, AMEC has essentially developed an approach for propagation loss model evaluation with the following characteristics:

• (U) Objective. A methodology has been developed which is applied to any model in a straightforward manner. Of particular note is the quantitative aspect of accuracy assessment. A recognized expert reviews and reports upon the physics and mathematical basis of the model.

• (U) Standardized. The same Model Information Form is to be utilized for all models and filled out by the model developer.* The same data bank is available for model/measurement comparison for any model to be evaluated making comparisons between models relatively easy. Even plot formats are standardized to facilitate model-to-model comparisons.

• (U) Rapid. Given the portable test package consisting of the Model Information Form, a computer program for quantitatively comparing two data sets (usually model output with measured values), and a set of environmental/acoustic scenarios (available on digital form), the evaluation of a model will now require approximately 10-12 months. This time should decrease with further experience.

(U) The benefits derived from evaluating models are threefold:

• (U) The limitations of a model and, hence, its domain of applicability are identified. The limitations may, in their basic form, arise from assumptions or approximations involved in the physics or mathematics, the computer implementation or characteristics of the computer, telemetry or graphics systems. These translate into limitations in frequency, range (for propagation loss models), or environment (e.g., flat ocean bottom). For example, run time or core limitations may reflect in frequency limitations for a normal mode propagation loss program. The small angle approximation inherent in the parabolic equation method of propagation loss prediction may result in invalid results at ranges where large bottom slopes are encountered. Knowing the domain of applicability of models is particularly important for those models in extensive fleet use, where a wrong answer may be worse than no answer. Such knowledge also indicates the need for other models and improvements.

• (U) Models may be improved through identification of model deficiencies and errors. In the course of model evaluations, errors in computer coding may be found. Even more likely is the discovery of model deficiencies, either by design (i.e., neglected features such as source or receiver beam pattern capability) or due to not choosing the best technique available for a given task. One model evaluation responsibility is to recommend upgrades or corrections to evaluated models. This function is extremely important, since it leads to improved versions of models with broader capabilities or increased accuracy or decreased core or run time requirements.

*The first two models evaluated, FACT PL9D and RAYMODE X, were not put through this process, since it was being developed during those models' evaluations. The information requested in the Model Information Form was, however, collected by the evaluators with the cooperation of the RAYMODE model developer and NORDA Code 320, which is responsible for FACT configuration management.

• (U) Models may be compared and, hence, the best selected for a given application. Given a number of models which have been evaluated through a standardized evaluation process, direct model-to-model comparison is rather easy and with the addition of information relating to specific aspects of the application not included in the AMEC evaluation, should lead to the selection of the best model.

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7. AUTHOR(s): Richard B. Lauer	8. CONTRACT OR GRANT NUMBER(s)
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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Model evaluation; Acoustic Model Evaluation Committee; AMEC; Propagation loss models; Underwater acoustic modeling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(U) The Acoustic Model Evaluation Committee (AMEC) has adopted an interim methodology for the evaluation of propagation loss models. The methodology consists of providing the following information: (a) model description, (b) physics and mathematics (c) run time, (d) core storage, (e) complexity of program execution, (f) ease of effecting program alterations, (g) program implementation on a different computer, (h) cognizant individual(s) or organization element(s), (i)byproducts, (j) special features, and (k) references. The accuracy of the

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model is assessed by quantitative measures of comparison with reference experimental data sets, other models, and closed form solutions. Two techniques are used: The difference technique, whereby differences between the model and a reference are statistically given in various regions (e.g. direct path, bottom bounce, convergence zone); and the Figure of Merit (FOM) technique, whereby detection coverage as given by the model and a reference data set are compared as a function of Figure of Merit. The basic intent of model evaluation is to provide model users, sonar system designers, and those who select models for use in making sonar system performance predictions with basic information on a model including its physical foundations, domains of applicability, software configuration, and machine dependencies so that the best match between acoustic model and sonar application may be achieved.

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Ser 93/160
10 Mar 99

From: Chief of Naval Research
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Ref: (a) CNMOC ltr 3140 Ser 5/110 of 12 Aug 97

Encl: (1) Listing of Known Classified PARKA Reports

1. In response to reference (a), the Chief of Naval Operations (N874) has reviewed a number of Pacific Acoustic Research Kaneohe-Alaska (PARKA) Experiment documents and has determined that all PARKA I and PARKA II reports may be declassified and marked as follows:

   Classification changed to UNCLASSIFIED by authority of Chief of Naval Research letter Ser 93/160, 10 Mar 99.

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3. Questions may be directed to the undersigned on (703) 696-4619, DSN 426-4619.

Peggy Lambert

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Continuation of LRAPP Final Report, February 1972, Contract N00014-71-C-0088, Bell Telephone Labs, Unknown # of pages
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